PAPERS ON CLIMATOLOGY IN RELATION TO AGRICULTURE, TRANSPORTATION, WATER RESOURCES, ETC.

THE COCONINO FOREST EXPERIMENT STATION NEAR FLAGSTAFF, ARIZ. G. A. Pearson, Director.

Summary from report prepared by A. E. HACKETT, Assistant Observer.

The largest pine forest on the North American Continent extends from north-central Arizona in a southeasterly direction into southwestern New Mexico, a distance of approximately 250 miles. The forest occupies an extensive plateau, known as the Colorado Plateau, which has a general elevation of from 6,000 to 8,000 feet above sea level, with numerous peaks the highest of which reaches an altitude of about 13,000 feet. Western yellow pine occupies the level mesas and lower slopes of the plateau from approximately 6,500 to 8,500 feet elevation, forming a belt 10 to 30 miles in width.

The timber of this region naturally grows in very open stands, the characteristic mode of occurrence being in small groups 80 to 300 feet in diameter, separated by openings of about the same size, but frequently there are much larger openings, some of them covering several hundred acres. These larger openings are commonly known as "parks". A number of theories have been advanced in explanation of the origin of the parks of this region. One is, that they were once timbered but have subsequently been denuded by fires. A more plausible theory in the case of most parks is that they are naturally treeless owing to the presence of conditions unfavorable to tree growth. With a view to determining these conditions, and also the influence of forest cover on reproduction, the Coconino Forest Experiment station, with the cooperation of the Weather Bureau, began, in 1908, a systematic study of the meteorological conditions obtaining in one of the larger parks, locally known as Fort Valley, and in the adjoining timber. This park lies about 8 miles northwest of Flagstaff, Ariz., on the Coconino National Forest, and is about 1½ miles in width by 2½ miles long, the major diameter extending northeast and southwest. The topography is practically level, and the average elevation approximately 7,300 feet above sea level. The soil is mainly a fine alluvial loam underlain at depths ranging from 1 to 2 feet by deposits of volcanic cinders. About one-forth of the land is under cultivation and the remainder is covered by a fairly dense growth of a low tufted grass. A moderately heavy forest of western yellow pine, opened in places by light cuttings, surrounds the park. The timber almost invariably occurs at a slightly higher elevation than the adjacent park land. In places the timbered area rises from the edge of the park in a very gentle slope, while in other places there is a rather abrupt rise of 25 to 100 feet. Occasionally narrow, slightly elevated tongues of timbered land extend out into the opening a distance of ⅛ to ¼ mile, and in two instances small isolated patches of trees occur on slight eminences well out in the park. The park and the surrounding timbered areas present the appearance of a partial basin. From 3 to 3½ miles north and east of the park begin the steep slopes of the San Francisco Mountains which, in a horizontal distance of from 1.9 to 2.5 miles rise from an elevation of 8,500 feet to an elevation of 12,340 feet, or approximately 5,000 feet above the level of the park. Minor peaks in the vicinity are Wing Mountain, about 2 miles northwest, and A–1 Mountain, at the southern edge of the park, with elevations of 8,500 and 8,300 feet, respectively. On the south and west sides the steep timbered slopes rise 200 or 300 feet above the park to a level mesa which here forms the rim of the basin.

The climate of this region which is fairly typical of the higher altitudes of Arizona and New Mexico, is characterized by great daily ranges of temperature and very marked seasonal variations in precipitation, atmospheric moisture, and wind movement. Owing to the rapid radiation incident to high altitudes the change of temperature from day to night is very great, occasionally amounting to 80°. The precipitation occurs mainly during the summer and winter months, the former season extending from about July 15 to September 10, and the latter from December to March, inclusive. During the summer rainy season, showers are very frequent and the relative humidity is usually high. During the winter months the precipitation is mainly in the form of snow, which frequently accumulates to a depth of 3 or 4 feet. As a rule but little precipitation occurs from April 1 to July1, and the wind movement and evaporation during these months are extremely high. This period is extremely trying on vegetation, especially forest seedlings which have not become well established. A similar, though unusually much less severe, period of drought extends from about September 10 to December 1.

Three meteorological stations were established on the western side of the Fort Valley park at which daily readings of temperature, precipitation, relative humidity, and wind movement have been made since January 1, 1909. Evaporation readings were also taken at all three stations from July 1 to October 31, 1909.

Station No. 1 is located in the edge of a projecting point of timber on the west side of the park, at an elevation of 7,261 feet.

The station is equipped with maximum and minimum thermometers, psychrometer, anemometer, wind vane, recording rain gage, and one evaporating pan. This station is protected by timber on the west and northwest, but receives the full force of the wind from other directions, especially the southwest, which is the prevailing wind direction in this region.

Station No. 2 is situated in the park 843 feet southeast of station No. 1, at an elevation of 7,247 feet. The instrumental equipment consists of maximum and minimum thermometers, psychrometer, anemometer, rain gage, and evaporation pan.

Station No. 3 is in a virgin stand of western yellow pine, 1,453 feet west from the edge of the park at an elevation of 7,348 feet. The equipment is the same as at station No. 2. At each of these stations the thermometers are exposed in louvered shelters, 4 feet above ground, and the anemometers are placed 8 feet above ground. The instruments were placed near the ground as it was desired to determine the conditions to which seedling growth is exposed. At the forest station the soil is a reddish, loamy clay, mixed with large volcanic boulders and the ground cover consists of a sparse growth of grasses and other herbs. Practically no leaf litter is found beyond 30 feet from the trees. The instruments are set in an opening 164 feet in diameter and are 66 feet from the nearest trees.

All of the instrument stations are situated slightly above the immediate surrounding country in order to secure good atmospheric drainage. The instruments have been read daily between 4 and 5 p. m. To determine whether or not the temperature conditions observed at stations 1, 2, and 3 were typical of the whole park and the adjacent timber on both sides, three temporary stations were established at which records were taken from January 25 to February 20, 1910. One of the stations was near the middle of the park, one-half mile east of station No. 2, at an elevation of 7,246 feet; another was in the park, 725 feet from the timber on the eastern side, elevation 7,264 feet, and the third was in a virgin stand of yellow pine 1,617 feet from the eastern edge of the park, at an elevation of 7,330 feet. Temperature records were obtained at these stations by means of thermographs checked by maximum and minimum thermometers, and indicated practically the same relation between forest and park temperatures as was found at the stations on the western side, except that on the eastern side the daily maximum temperatures were slightly higher in the forest than in the park, while on the western side the reverse was the rule. At these temporary

stations the thermometers and thermographs were exposed in improvised shelters open on the north side.

Table 1 presents a summary, by months, of the temperature records at stations Nos. 2 and 3 for the year 1909.

TABLE 1.—*Summary of temperature observations at Coconino Forest Experiment Station.*

Month.	Mean maximum.		Mean minimum.		Monthly mean.		Highest.		Lowest.		Mean daily range.	
Station.....	2	3	2	3	2	3	2	3	2	3	2	3
	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F
January.....	43.5	43.5	14.7	20.8	29.1	32.2	56	52	−14	4	28.8	22.7
February.....	42.2	42.3	6.6	13.8	24.4	28.0	53	50	−20	− 2	35.6	28.5
March.....	42.0	42.1	10.8	18.7	26.4	30.4	51	51	−19	− 4	31.2	23.4
April.....	56.3	56.1	21.0	24.8	38.6	40.4	69	65	9	14	35.3	31.3
May.....	64.7	62.7	26.2	29.4	45.4	46.0	81	70	17	21	38.5	33.3
June.....	77.1	77.0	33.3	40.5	55.2	58.8	87	90	25	32	43.8	36.5
July.....	78.2	78.0	44.2	49.4	61.2	63.7	89	90	32	39	34.0	28.6
August.....	72.6	72.4	48.0	50.6	60.3	61.5	79	79	42	47	24.6	21.8
September.....	69.4	68.5	36.6	41.5	53.0	55.0	77	75	25	31	32.8	27.0
October.....	65.9	64.4	19.7	29.1	42.8	46.8	75	72	5	13	46.2	35.3
November.....	53.7	53.2	11.2	20.8	32.4	37 0	79	67	−20	− 1	42.5	32.4
December.....	38.7	36.4	−1.0	9.1	18.8	22.8	58	52	−28	−12	39.7	27.3
Year.....	58.7	58.9	22.6	29.0	40.6	43.6	.....	.....	.....	.....	36.1	29.0

Station No. 2 is in the open park. Station No. 3 is in the virgin forest.

identical. The difference between the records in the forest and in the park in clear weather are less pronounced in summer than in winter.

In seeking to account for the great difference between the minimum temperatures of the forest and the park, the first factor to suggest itself is the difference in radiation. The change of temperature from day to night is usually very great at this altitude, owing to excessive radiation, and it is possible that the tree crowns may exert a sufficient retarding influence upon the loss of heat to noticeably effect the tempreature of the forest. This opinion is supported by the fact that in cloudy weather when radiation is reduced to a minimum the lowest temperatures recorded in the timber are about the same as those recorded in the park. But, while it is very probable that the tree crowns do retard radiation to a marked degree, when we consider that in a western pine forest the trees actually cover not more than one-half of the total area, and that in this investigation the thermometers are exposed in a small opening instead of directly under the trees, it seems doubtful whether the effect of the crowns would be sufficient to account for the great differences in temperature that have been observed.

The fact that the park is slightly below the surrounding timbered areas suggests the idea that the cold air of the vicinity set-

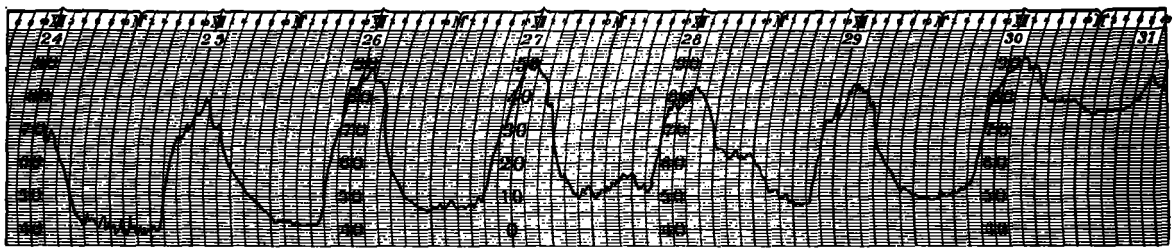

FIG. 1.—Thermogram at Station No. 3 (Forest), December 24–31, 1909.

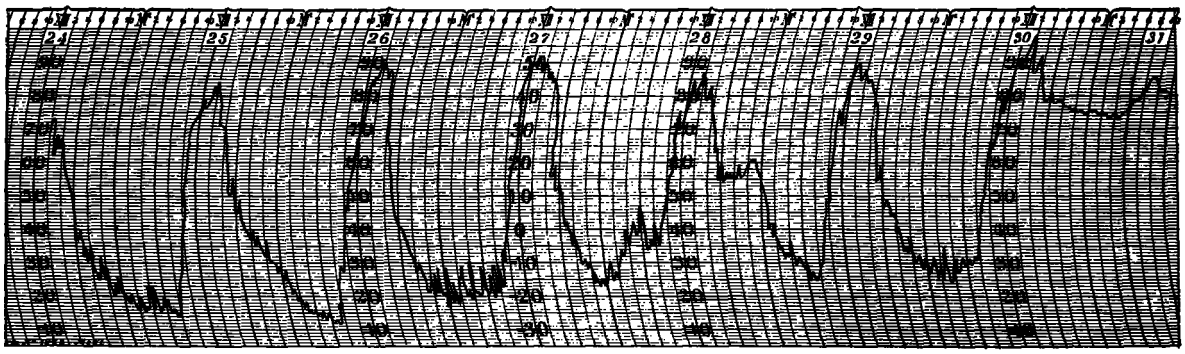

FIG. 2.—Thermogram at Station No. 2 (Park), December 24–31, 1909.

A comparison of the monthly means of temperature shows a slightly lower mean maximum, but a much higher mean minimum, in the forest then in the park, which has the effect of increasing the monthly mean and increasing the range in the forest. This relation holds throughout the year but, with the exception of the month of June, it was decidedly more marked during the winter than during the summer. The most striking difference is in the extreme minima, which are commonly from 10° to 16° higher in the forest than in the park.

The relation between the forest and park temperatures in clear weather is strikingly shown by the thermograph curves in figures 1 and 2. The curves for the forest (fig. 1) show, in addition to a much smaller daily range, less pronounced minor fluctuations and a more gradual change from one extreme to the other. In cloudy weather the curves for forest and park are practically

tles into the park, thereby reducing the temperature near the surface of the ground in the park much below that of the forest. But since the immediately surrounding forest, where the stations are located, is considerably below the country back of it and only a few feet above the park, it seems that any cold air drainage from the surrounding mountains and mesas should make itself felt at the forest as well as at the park station. Another explanation of these conditions lies in the possible resistance offered by the forest to the atmospheric drainage from the San Francisco Mountains. The cold air of the upper mountain slopes would naturally settle into the valley below, thereby causing a general movement away from the mountains. This cold air in passing over a timbered area might be prevented to a certain extent by the tree crowns from mixing freely with the warmer air below, or underrunning it, being diverted over the tree tops

into the open park. Automatic records of wind direction at station No. 1 indicate that there is a movement of air from the San Francisco Mountains toward the valley at night.

The great differences in temperature observed are probably due to a combination of the two causes mentioned, the drainage of cold air from the steep slopes of the mountains undoubtedly playing an important part in the reduction of the temperature in the park. However, the same conditions will probably be found to exist in practically all of the parks in the forest since they are nearly all lower than the country immediately surrounding them.

The records of wind movement at stations Nos. 2 and 3 show that the average wind velocity is about twice as great in the park as in the forest.

The mean daily evaporation in the forest for the 4 months, from July 1 to October 31, was from 65 to 77 per cent of that in the park. The decreased evaporation in the forest is undoubtedly due to the decreased wind movement.

The protective influence of the forest on vegetation is strikingly illustrated by two small plantings of western yellow pine at meteorological stations Nos. 1 and 3. Fifty 2-year-old plants were set at each of these stations on April 22, 1909. On May 21, 90 per cent of the plants at station No. 3 were alive, while at station No. 1 only 11 per cent were alive. Soil samples taken on the same date showed a moisture content of 17 per cent at station No. 3, and 17.5 per cent at station No. 1, indicating that at both places the available soil moisture was ample to keep the plants alive. Nevertheless the appearance of the dead seedlings pointed to drought as the cause of their death. No records of evaporation are available for this period, but the wind movement at station No. 1 was practically twice as great as at station No. 3; there was but little precipitation, and the sky was generally clear. The inference is, therefore, that the plants at the edge of the forest, owing to the excessive evaporation, dried up in spite of the presence of abundant moisture at the roots, and that the relatively small loss in the forest was due to the protection against evaporation.

On large portions of the western yellow pine forests of this region the most serious silvicultural problem which the forester has to meet is that of regeneration, and the practical value of a forest cover in moderating two of the extreme physical conditions most unfavorable to forest regeneration, namely, excessive evaporation and, to a certain extent, frost, has been demonstrated by the observations at Fort Valley.

THE PETRIFIED FORESTS OF ARIZONA.

By Prof. F. H. BIGELOW.

In view of the interest in the subject of forests and climatology, it may be proper to recall a few of the well-known facts regarding the petrified forest in northern Arizona. A high escarpment of land, about 5,700 feet above sea level, stretches from Utah into northern Arizona. The Colorado River has cut its gorge across this escarpment, and to the southeast of the Colorado extends the plain of the Little Colorado on the top of this plateau the surrounding region being generally known as the Painted Desert. The Atchison, Topeka and Santa Fé Railroad crosses the escarpment to the south of the Grand Canyon, by way of Flagstaff, Holbrook, and Adamana. The station Adamana lies between the Rio Puerco and the Rio Zuni. About 10 or 15 miles south of the railroad station Adamana lies the famous petrified forest. It consists, as shown in the accompanying photographs (figs. 1–6), of massive tree trunks, generally coniferous, some from 100 to 200 feet in length and as much as 4 feet in diameter. Others are broken up into large blocks and scattered around quite irregularly. The entire country has been heavily eroded, so that the original horizontal plain, in which these trees grew, remains in only a few isolated places. However, the roots and some of the tree trunks, imbedded in the original soil, seem to have been found, the inference being that there has been no important transfer of the logs horizontally, such as would occur if they were floated in the water of the ancient rivers or seas, or such as would result from their rolling down the embankments into one place during the erosion of the region into high and low levels. The climatological history of this ancient forest is, of course, unknown, but it is inferred by Prof. F. Ward, who examined the region, that the trees must have grown in the Mesozoic or Triassic ages, so that they are many millions of years old. These tree trunks have now been transformed into agate, jasper, and chalcedony,

FIG. 1.—Eagle's Nest Rock. The pinnacle shows the height from which the entire region has been eroded by recent water action.

and their colors are very beautiful. Apparently they were submerged in the ancient waters, covered with sand, which on hardening embraced the logs and gradually turned them into stone by the absorption of silicates in solution. The region was then elevated probably from some low elevation as sea level to the height of nearly 6,000 feet, and the wearing away of the country through erosion has left them in their present condition.

The history of the Great Salt Lake, which is a remnant of the greater lake, Lake Bonneville, once about as large as Lake Michigan, this being of recent geological age, indicates that the entire region of the western portion of the United States was altogether different in its formation from what we now know it. The Rocky Mountains on the eastern side of the plateau apparently bore something of the same relation to the prevailing westerly winds that the Sierra Nevada Mountains now do to the Pacific Ocean and its winds, the Sierra Nevada Mountains